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COMBINATORIAL GEOMETRY COMPUTER MODELS OF SITTING AND STANDING CREW PERSONNEL

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August 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Revised computer descriptions (models) of sitting and standing crew personnel have been generated using the Combinatorial Geometry (COM-GEOM) technique. These personnel models have been validated and have limited capability to be moved into various positions dependent on analytical requirements. The models generally correspond to the anthropometric data from the 50-60 percentile grouping of US Army males. Appendix A discusses the calculation of an average human density based on the densities of bony and soft tissue.

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I. INTRODUCTION

New computer models of sitting and standing crew personnel have recently been constructed and are currently available for use in modifying and developing descriptive computer models of a variety of military systems considered for vulnerability analysis. The background for the generation of the computer models for the sitting and standing crew personnel grew out of training exercises involving the learning of the Combinatorial Geometry (COM-GEOM) technique of modeling milita target systems.

Initially, approximately three years ago, the human head was selected as a subject for such a training exercise. The COM-GEOM model of the human head was subsequently completed and has remained, unuseful in its present state, until more recently, when the decision was made to complete the remainder of the crewman model. This decision evolved during the past year when the need appreciated for models of crew personnel that were more consistent with the level of detail in the COM-GEOM military target models currently being developed.

The new crew personnel models presented in this report are more anatomically detailed than the previously used models. This represents an improvement since the new models are more realistic and technically correct. However, this does not mean that the new models should be used for detailed studies involving human wound ballistics; further improvements in model detail could make such studies possible.

The sitting and standing crew personnel models were developed in two configurations, helmeted and unhelmeted, available in both inch and millimetre dimensional units. (The helmet is the only protective gear incorporated into the models.) Additionally, these models were developed with a feature which will allow them to be moved into various realistic positions; this will be discussed in a following section.

II. COMBINATORIAL GEOMETRY (COM-GEOM) MODELING TECHNIQUE

The generation of the computer models of the sitting and standing crew personnel utilize the COM-GEOM techniques of generating three dimensional models of objects. This technique provides compatible input data required to implement the Geometric Information for Targets (GIFT) computer code. Detailed discussion of the GIFT computer code and its many options are beyond the scope of this report; however, accounts of the COM-GEOM technique and its relationship to the GIFT code can be found in BRL Report No. 1802[1] and ARBRL Report No. 02189[2].

---

[1] Lawrence W. Bain, Jr., and Mathew J. Reisinger, "The GIFT Code User Manual; Vol. I, Introduction and Input Requirements," USA Ballistic Research Laboratory Technical Report No. 1802, July 1975, DA#B006037L.

[2] Gary G. Kuehl, Lawrence W. Bain, Jr., and Mathew J. Reisinger, "The GIFT Code User Manual; Vol. II, The Output Options," USA Ballistic Research Laboratory Report No. 02189, Sept 1979, AD#A078364.

Only a brief familiarization with the COM-GEOM technique and terminology will be presented here.

The COM-GEOM technique provides up to twenty-three different types of basic geometric solids which may be assembled in combinations, as building blocks, to represent or "describe" a three dimensional (3-D) object. The geometric solids are combined in a prescribed manner, using selective set theory operations to generate the regions defining external and internal details of the 3-D object, such as shape, size, and location of various parts or components. The COM-GEOM computer model (description) contains three separate tables containing:

- Parametric data relating to the generation of the geometric solids comprising the model,
- Region data formed by the specific combination of the geometric solids, and
- Region identification data in which the regions are described verbally and given a specific numeric item descriptor.

The geometric solids available for use (and recognizable to the GIFT code) are listed in Table I. Parameters for each type of geometric solid listed must be tabulated in the manner prescribed in Reference 1. These parameters include characteristics which define the solid's physical size and exact location and orientation within a specified coordinate system.

There are no restrictions on the selection of geometric solids used in the modeling of an object. Ideally, a minimum number are used which would be sufficient to represent the level of detail desired for a specific model. Tables B-I and C-I list the geometric solids and their parameters used for the models of sitting and standing crew personnel respectively.

In forming the various components comprising a complex 3-D object, individual geometric solids are combined to form regions. A region is the volumetric space occupied by single or multiple solids. Solids are combined according to the following three set theory operations:

- Intersection (designated by a plus sign, +),
- Union (designated by an OR), and
- Subtraction (designated by a minus sign, -).

The Intersection (+) of two or more geometric solids defines the volumetric space common to the solids. The Union (OR) of two or more geometric solids defines the volumetric space within all the solids involved. The Subtraction (-) of two or more geometric solids defines

Table I. List of Geometric Solids Utilized in COM-GEOM Descriptions

Symbol for Solid Type	Solid Description
RPP	Rectangular Parallelepiped
BOX	Box
SPH	Sphere
RCC	Right Circular Cylinder
REC	Right Elliptical Cylinder
TRC	Truncated Right Angle Cone
ELL ELL1	Ellipsoids of Revolution (Input data differs slightly in ELL1)
ELLG	General Ellipsoid
RAW	Right Angle Wedge
ARB4	Arbitrary Convex Polyhedron of Four Sides
ARB5	Arbitrary Convex Polyhedron of Five Sides
ARB6	Arbitrary Convex Polyhedron of Six Sides
ARB7	Arbitrary Convex Polyhedron of Seven Sides
ARB8	Arbitrary Convex Polyhedron of Eight Sides
ARBN	Arbitrary Convex Polyhedron of N Sides
TEC TEC1	Truncated Elliptical Cones (Input data differs slightly in TEC1)
TGC	Truncated General Cone
HAF	Universe Dividing Plane
AQS	Arbitrary Quadratic Surface
TOR	Torus
ARS	Triangular Surfaced Polyhedron

the volumetric space contained in the first solid minus the volumes of the other intersecting solids. A two-dimensional analogical illustration displaying the effects of these three operations on three interacting solids is shown in Figure 1. Theoretically, any number of geometric solids may be used to define a region. In practice, regions are usually defined as representing some relatable component or part of a complex object. Each unique region with the combination of geometric solids defining it, are listed in the region data table. Tables B-II and C-II list the regions used in the sitting and standing man, respectively.

Each region of the model is assigned additional identification in the form of coded identification numbers and descriptive comments. The first of the coded identification numbers, termed an Item number, indicates the type or classification of the component the region represents. In most computer models of weapon systems regions are usually grouped according to the functions the involved components perform. Examples of such conventional groupings would be the missiles and cannisters and electrical and electronic components of a missile system. These groupings are usually designated by a three digit series number with the same first digit for the entire group. Another coded number assigned to a region indicates whether the region represents a volume of air; if greater than zero, it is either internal air somewhere within a target system or external air. Here again, certain conventions are used to distinguish the various air codes. Since the computer models of crew personnel are not as complex as models of weapon or other target systems, the coded identification numbers are not utilized to their fullest extent. The region identification table also allows up to 40 alphanumeric characters which will be used for a verbal description of the region. Associated with this description are two additional coded numbers indicative of the type of material the region is basically made of and a percentage number associated with an equivalent line-of-sight (LOS) thickness of the region. These latter numbers are required input for a typical vulnerability analysis. Tables B-III and C-III list in numerical order the regions and their appropriate identification. Tables B-IV and C-IV list the regions and their identification numbers ordered by Item numbers.

Tables B-I, B-II, and B-III and C-I, C-II, and C-III form the complete COM-GEOM computer models of the sitting and standing crew personnel, respectively.

III. COM-GEOM MODELS OF CREW PERSONNEL

The computer models of the sitting and standing crew personnel represent combat soldiers approximately 1.75 metres (5 feet 9 inches) in height with body measurements scaled from men of average mesomorphic proportions. Initial measurements used for these models were generated independently, unbiased by those of the previous computer models of sitting and standing man. It was noted that some measurements on both the previous and new models were very similar in size. The initial

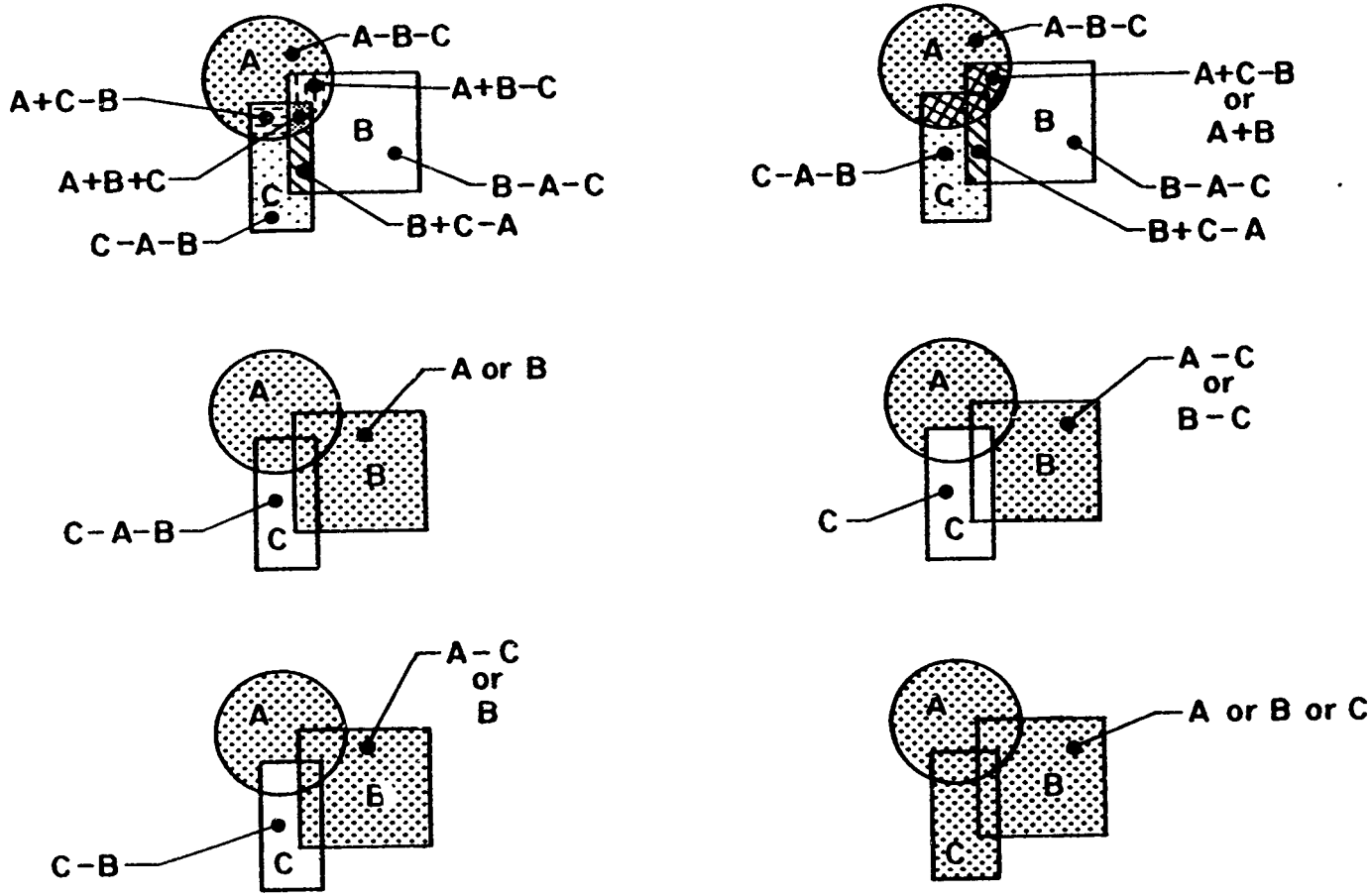


Figure 1. Regions (·) Formed When Using Intersection (+), Union (OR), and Subtraction (-) Operations on Three Interacting Solids

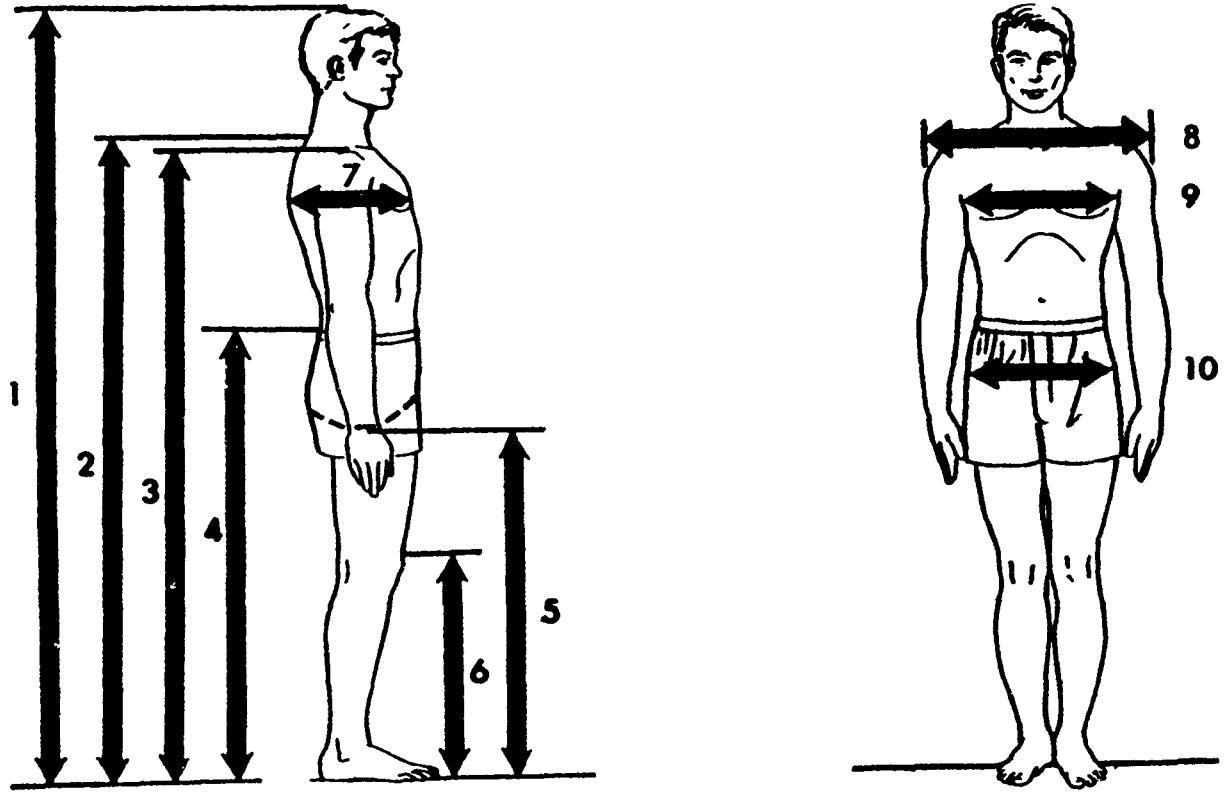
measurements for the new models were taken from male Ballistic Research Laboratory personnel and adjusted on the basis on what was considered to be "average." Later adjustments were made based on anthropometric data for US Army soldiers.[3] Figures 2 and 3 indicate which basic measurements were used in the adjustment process. The comparison of the measurements from actual US Army soldiers and the computer models is shown in Table II. The measurement data from the data from the soldiers represent the 50th and 75th percentile grouping. As indicated in Table II, most of the measurement data for the computer models varies somewhat between these two groupings, but tends toward the 50th percentile grouping. Bodily regions, as described in the models, are consistent with those defined in the currently accepted "computer man" model developed by the Research Division of Chemical Systems Laboratory at Edgewood. The calculation of the weight for the computer models is based on MOMENT Subroutine calculations for the total volume of the computer models. Details regarding weight calculations are discussed in the following section and Appendix A.

The origin of the coordinate system used for these models are located within the heads of the models, at a point centered between the eyes, the forehead, and the rear of the head; it is located 48.26 millimetres (mm) (1.9 inches) above the eyes. Figure 4 and 6 display the front and side views of the graphical representatives of the models of sitting and standing man, respectively, complete with location of the center of their coordinate system and direction of the positive coordinate axis. The height of the center of coordinates is also shown. Figures 5 and 7 display the front and rear oblique views of these models, indicating additional detail. Dimensions pertinent to the space or volume required for emplacement of these models within a weapon or target system model can be obtained from Table II. Two versions of the models of sitting and standing man were prepared, helmeted and unhelmeted. The helmeted version of sitting man contains 56 solids and regions, while the unhelmeted version contains 50. Similarly, the helmeted version of standing man contains 62 solids and regions, while the unhelmeted version contains 56. Consistent with the units of measurement used in both past and current weapon system models, the crew personnel are available in either inch or millimetre dimensions.

IV. VALIDATION PROCEDURE

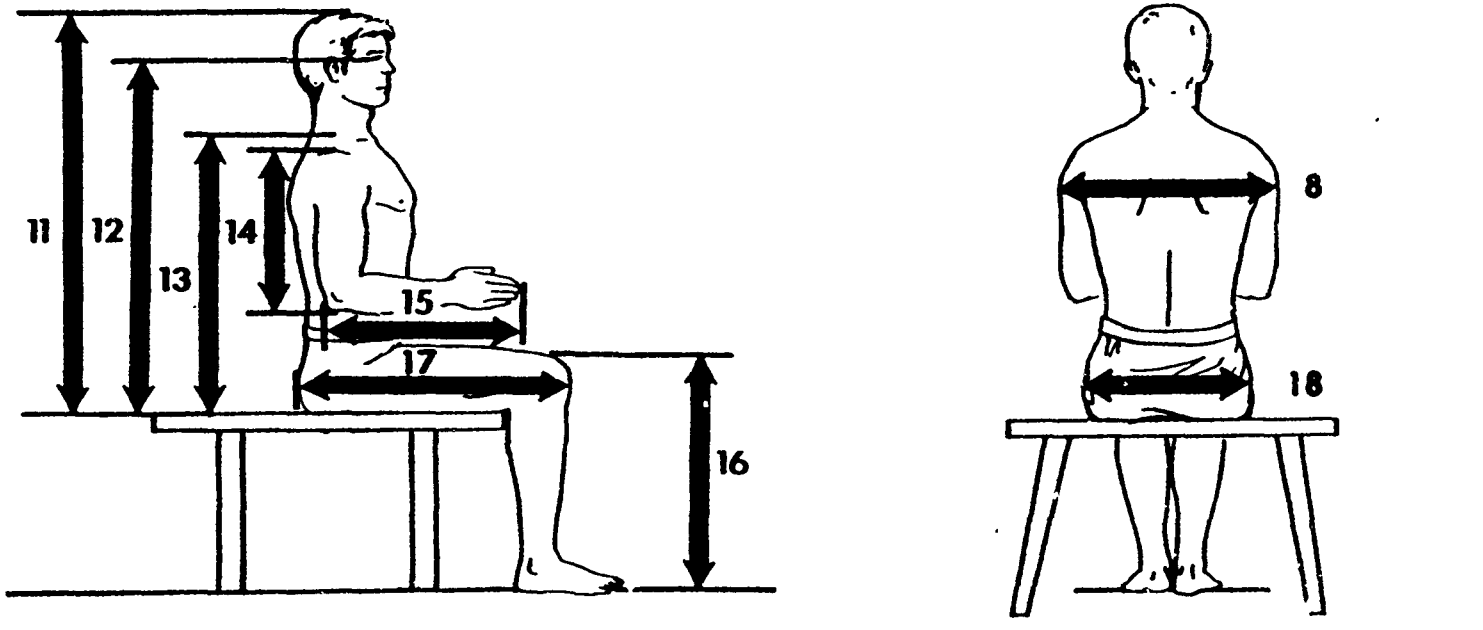
The validation procedure entails a series of steps which are designed to verify that the COM-GEOM computer models are correctly prepared, that is, valid. The series of steps begins with the application of the CHECK Subroutine of the GIFT computer code. The CHECK Subroutine determines whether regions overlap, that is, occupy the same volume within the computer model. A 0.25 mm allowable overlap tolerance, defined as the maximum amount which the components can overlap, was used in the CHECK analysis of these models. Overlaps noted by this step were subsequently corrected.

[3] Robert M. White, "The Body Size of Soldiers; US Army Anthropometry - 1976," US Army Natick Laboratories Technical Report No. 72-51-CE, December, 1971.



1. Stature Height
2. Cervical Height
3. Shoulder Height
4. Waist Height
5. Crotch Height
6. Kneecap Height
7. Chest Depth
8. Shoulder Width
9. Chest Width
10. Hip Width, Standing

Figure 2. Numerical Indices for Various Measurements Taken from Actual Standing US Army Soldiers



8. Shoulder Width (see Fig. 2)
11. Sitting Height
12. Eye Height, Sitting
13. Mid-Shoulder Height, Sitting
14. Shoulder-Elbow Length
15. Elbow-Fingertip Length
16. Knee Height, Sitting
17. Buttock-Knee Length
18. Hip Width, Sitting

Figure 3. Numerical Indices for Various Measurements Taken from Actual Sitting US Army Personnel

Table II. Comparison of Anthropometric Measurements from US Army Soldiers and Measurements from Computer Models of Sitting and Standing Personnel

Measurement Type		Measurement Data [millimetres (inches)]			
Index[1]	Description	50th Percentile Soldier	Computer Models Standing	Computer Models Sitting	75th Percentile Soldier
-	Weight[2]	70.7 (156)	72.12 (159)	75.60 (167)	78.47 (173)
1	Stature Height	1745 (68.7)	1756 (69.1)	1773 (69.8)[3]	1788 (70.4)
2	Cervical Height	1494 (58.8)	1488 (58.6)	---	1539 (60.6)
3	Shoulder Height	1438 (56.6)	1445 (56.9)	---	1478 (58.2)
4	Waist Height	1064 (41.9)	1036 (40.8)	---	1102 (43.4)
5	Crotch Height	838 (33.0)	828 (32.6)	---	871 (34.3)
6	Kneecap Height	528 (20.8)	508 (20.0)	---	551 (21.7)
7	Chest Depth	231 (9.1)	216 (8.5)	---	244 (9.6)
8	Shoulder Width	452 (17.8)	508 (20.0)	---	470 (18.5)
9	Chest Width	305 (12.0)	356 (14.0)	---	320 (12.6)
10	Hip Width, Standing	330 (13.0)	338 (13.3)	---	345 (13.6)
11	Sitting Height	907 (35.7)	---	904 (35.6)	932 (36.7)
12	Eye Height, Sitting	787 (31.0)	---	792 (31.2)	813 (32.0)
13	Mid-Shoulder Height Sitting	525 (24.6)	---	638 (25.1)	645 (25.4)
14	Shoulder-Elbow Length	368 (14.5)	---	356 (14.0)	381 (15.0)
15	Elbow-Fingertip Length	478 (18.8)	429 (16.9)	351 (13.8)[4]	495 (19.5)
16	Knee Height, Sitting	541 (21.3)	---	556 (21.9)	559 (22.0)
17	Buttock-Knee Length	594 (23.4)	---	597 (23.5)	612 (24.1)
18	Hip Width, Sitting	340 (13.4)	---	356 (14.0)	356 (14.0)

[1] *See Figures 2 and 3*

[2] *Weight is stated in units of kilograms and pounds ( ).*

[3] *This is the height of Sitting Man if he were erected to a standing position.*

[4] *Hand is in a clenched position.*

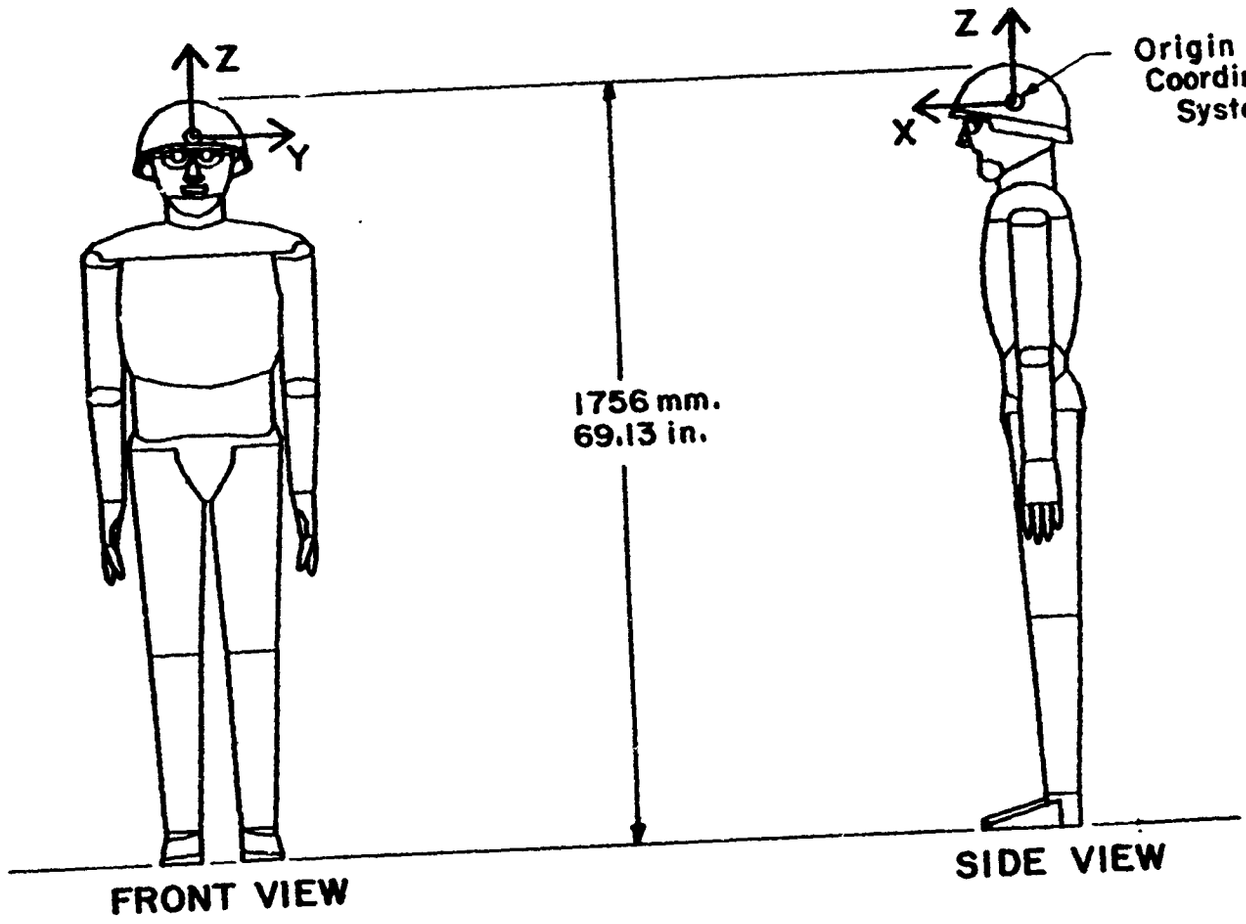


Figure 4. Front and Side Views of the Model of Standing Man with Helmet Showing Orientation and Origin of Coordinate System

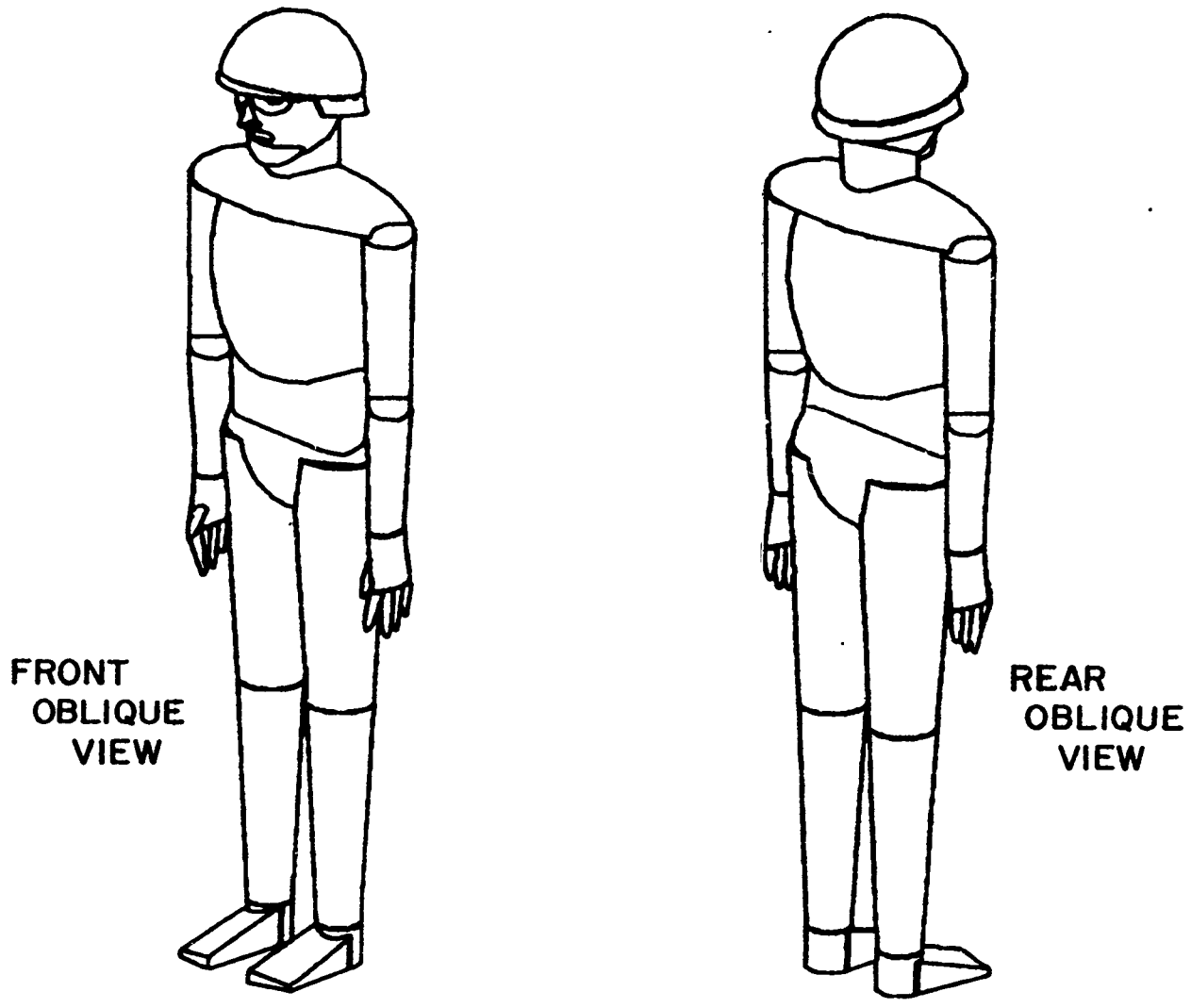


Figure 5. Oblique Views of the Model of Standing Man with Helmet

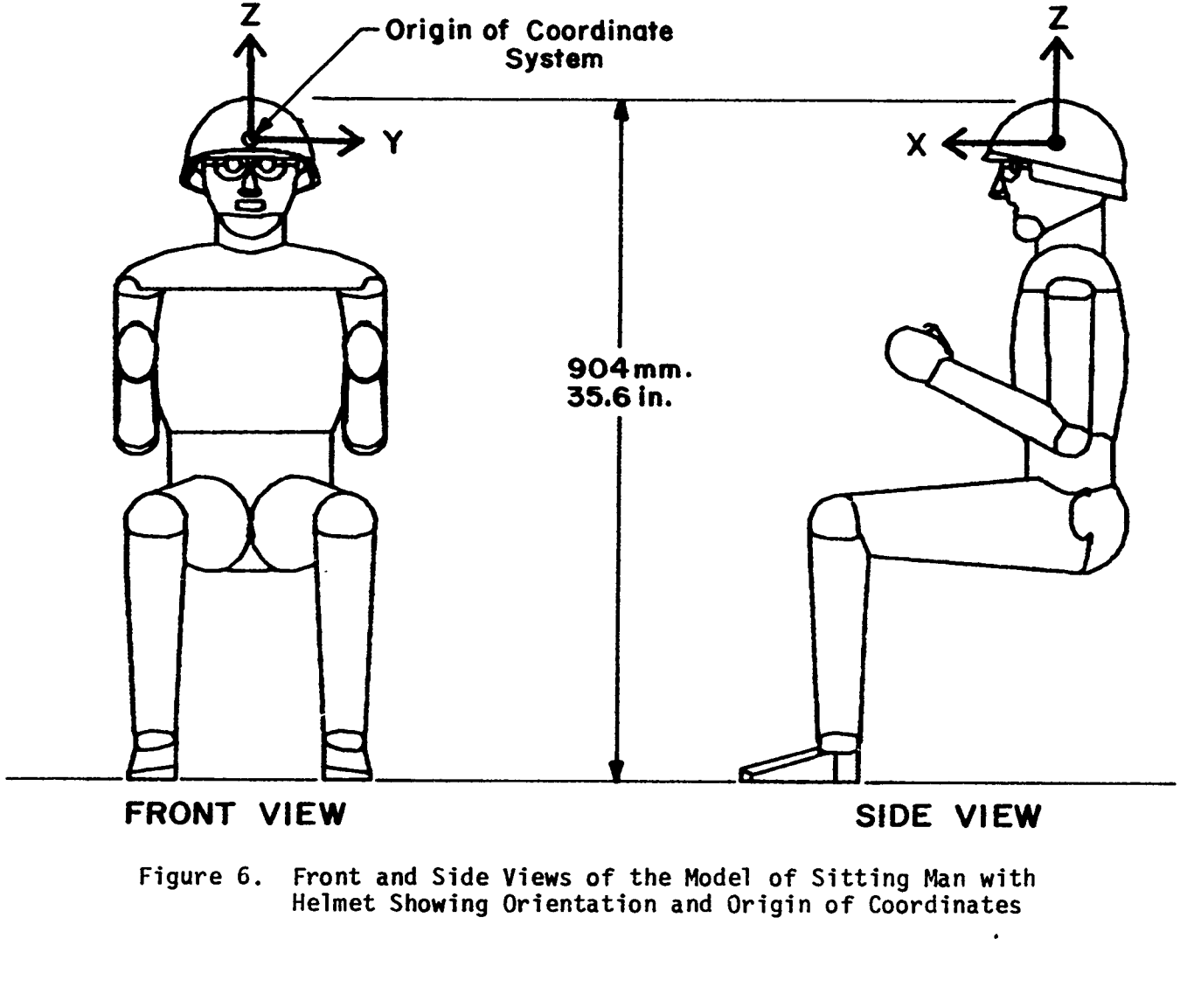


Figure 6. Front and Side Views of the Model of Sitting Man with Helmet Showing Orientation and Origin of Coordinates

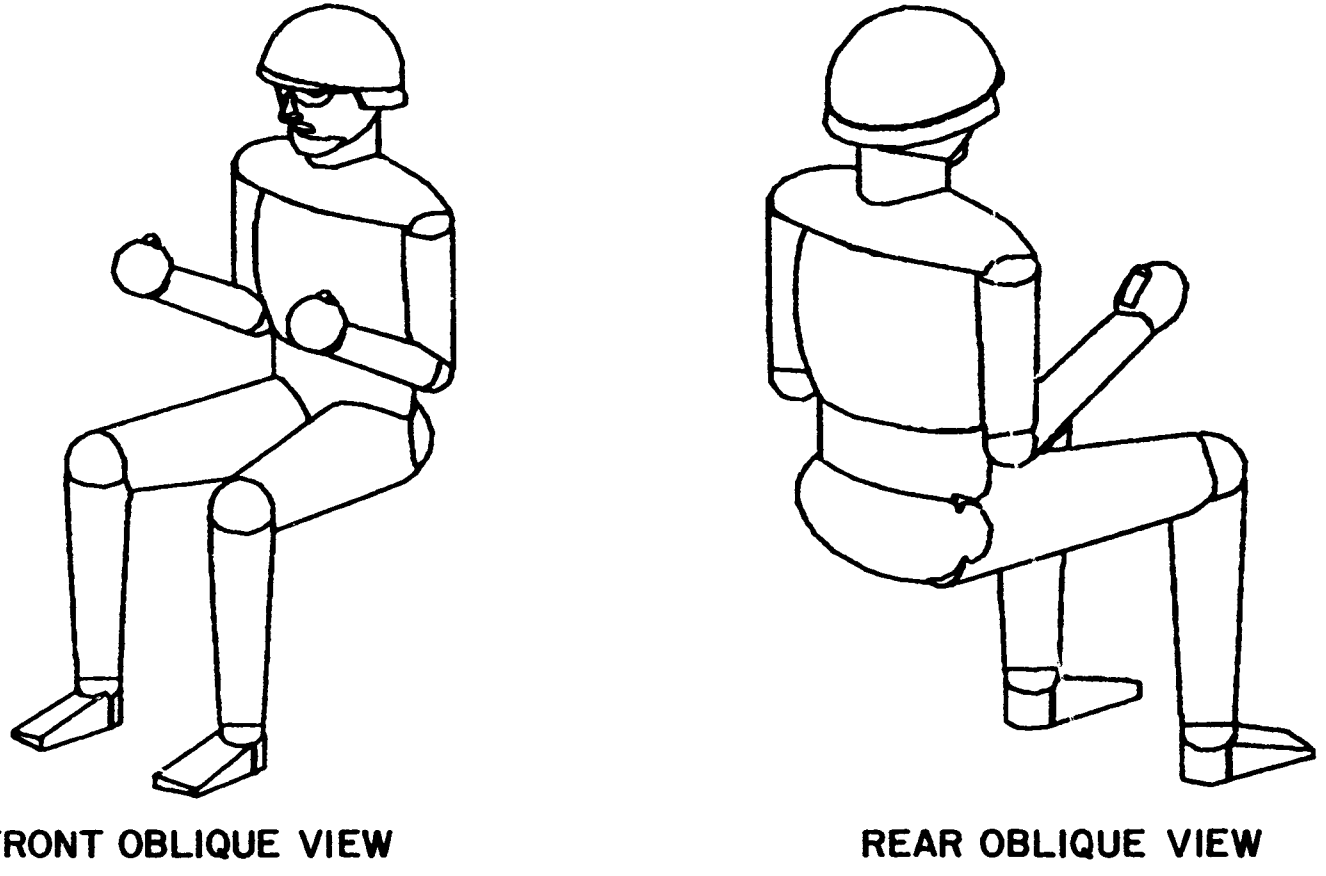


Figure 7. Oblique Views of the Model of Sitting Man with Helmet

The second step of the validation procedure uses the GRID Subroutine to determine whether unwanted voids or undefined volumes exist in the computer model; it does this by examining the model in fine detail from various directions. The GRID Subroutine passes a plane, which is perpendicular to the attack aspect under consideration, through the origin of the computer model's coordinate system. A grid overlay is then superimposed on this plane and for each cell on this grid overlay, a ray, normal to the attack plane, is projected through the computer model. As each ray is traced through the computer model, LOS thickness, normal thicknesses, and the obliquity angles are enumerated for every Item encountered along the ray path. Voids highlighted by this step are then corrected.

A third step in the validation procedure involves the use of the MOMENT Subroutine of the GIFT computer code. The MOMENT Subroutine also projects rays through the model but with the intent of producing estimates of weights of components based on individual component (Item) densities. Moments of inertia along with total weight and volume of the model are also calculated in this subroutine. The component (Item) densities are the key input data in exercising the MOMENT Subroutine; calculations of all other values are dependent on the accuracy of these data. However, often exact density values are not available because the component is comprised of more than one material (non-homogeneous) or it has a shape or volume that is irregular. In the case of components having internal air spaces, LOS percentages of solid material to air must be considered; this determines how the density must be "adjusted" to correctly calculate a total component weight. The analyst adjusts the density on successive computer runs so that the individual component weights correspond, within a desired tolerance, to their actual weights.

Since there are no density values available for the individual body regions, as defined in these models, an average density of 1.07 gm/cm^3 was initially used for all of the body components. (The density of 1.07 gm/cm^3 is the accepted density value for soft tissue of the human body.) Analysis of the MOMENT output data, using densities of 1.07 gm/cm^3, indicated that, for the volume and height, the models of the sitting and standing crew personnel were too light in weight. Subsequently, it was determined that the average density used for the personnel models was not large enough and a new algorithm, based on the density of soft tissue and bone, should be used. This algorithm, derived in Appendix A is based primarily on the percentage values, by weight, of bone and muscle within an average human body and the total body volume as calculated by the MOMENT Subroutine. The total weights and final "adjusted" density values used for all the components of sitting and standing man as calculated by this new algorithm are as follows:

	Density (gm/cm^3)	Body Weight (kg)
For Sitting Man	1.1843	75.60 (167 lbs)
For Standing Man	1.1794	72.12 (159 lbs)

Using these density values, the total weights were verified by the MOMENT Subroutine. The differences in the body densities and weights, shown above, are accounted for by the slight differences in the total body volumes of the sitting and standing personnel models as calculated by the MOMENT Subroutine.

Another step in the validation procedure consists of the generation of computer graphic illustrations of the model, as produced by the PICTUR Subroutine of the GIFT computer code. These computer illustrations are examined in detail to determine if all regions are in their proper position. Figures 4 through 7 represent computer illustrations produced by the PICTUR Subroutine.

V. MODEL UTILIZATION INFORMATION

The computer models of sitting and standing crew personnel were constructed so that the geometric solids comprising the arm and legs could be moved selectively into more realistic positions, if required. To facilitate any required movement (rotation) of geometric solids, pivot points corresponding to various body joints were designated. However, in regard to the pivot points, the models of sitting and standing man are slightly different: only the model of sitting man has knee and ankle joints. Pivot points and their coordinate values are listed for both models in Table III. Body positions involving the movement of the back (either bends or twists) have not been designed for the models.

The validated computer models of sitting and standing crew personnel are available in English (inch) and metric (millimetre) dimensions and are currently accessible on the CYBER 76 computer. The authors express sincerely the opinion that the use of these models of crew personnel will enhance and increase the credibility of current weapon or target system models.

Table III. Coordinates of Selected Pivot Points Within Models of Sitting and Standing Crew Personnel.

Description of Pivot Point	X, Y & Z Values For Pivot Points (mm)					
	Sitting Crewman			Standing Crewman		
	X	Y	Z	X	Y	Z
Base of Neck (for head movements)	-25.40	0.0	-241.30	-25.40	0.0	-241.30
Shoulders (shoulder joint)	-25.40	±209.55	-292.10	-25.40	±209.55	-292.10
Elbows	-25.40	±215.90	-577.85	-25.40	±215.90	-609.60
Hips (base end of thigh)	-44.45	±69.85	-746.13	-38.10	±84.14	-739.38
Knees	407.35	±178.42	-746.13	-----	-----	-----
Ankles	407.35	±178.42	-1168.40	-----	-----	-----

ACKNOWLEDGMENT

The authors gratefully acknowledge the contributions of Mr. David Neades, for the data he furnished and for the discussions which led to the analysis within Appendix A.

APPENDIX A

CALCULATION OF "ADJUSTED" WEIGHT AND DENSITY OF THE CREW PERSONNEL MODELS

CALCULATION OF ADJUSTED WEIGHT AND DENSITY OF THE CREW PERSONNEL MODELS

(Based on the Volumes Computed by MOMENT Subroutine)

Initially, if one makes the assumption that the human body is comprised basically of two kinds of tissue, bone and soft tissue (which includes all the muscles, internal organs, etc.), then, the total volume of the human body (V_{HB})[1] can be expressed as the volume of bone (V_B) plus the volume of soft tissue (V_{ST}). This relationship is shown as:

$$V_{HB} = V_B + V_{ST} \qquad (1)$$

The MOMENT Subroutine computed only V_{HB}; V_B and V_{ST} are not known and must be determined from other quantities.

V_{HB} (for sitting man) = 63835.05 cm^3 (2.2543 ft^3)

V_{HB} (for standing man) = 61147.76 cm^3 (2.1594 ft^3)

The total weight of the human body (W_{HB}) is expressed as the weight of bone (W_B) plus the weight of soft tissue (W_{ST}), or

$$W_{HB} = W_B + W_{ST}. \qquad (2)$$

However, the percent of bone by weight[2] in an average adult human body is a known quantity and may be used as the basis for determining W_{HB},

$$\% \text{ Bone}_{HB} = \frac{W_B}{W_{HB}} = 43 \qquad (3)$$

and

$$\% \text{ Soft Tissue}_{HB} = \frac{W_{ST}}{W_{HB}} = 57. \qquad (4)$$

---

[1] Subscripts B, ST, and HB represent Bone, Soft Tissue, and Human Body, respectively. They are used throughout the appendix.

[2] The percent of bone by weight in an average human body determined to be 43%. Ref: Dave Neades (undisclosed source).

W_{HB}, W_B, and W_{ST} are, at this point, undetermined; but

$$W_B = V_B \rho_B$$

and

$$W_{ST} = V_{ST} \rho_{ST}$$

where

$\rho_B = 1.8$ gm/cm^3 (This represents an average from a range of densities between 1.7 - 2.0 gm/cm^3.)

and

$\rho_{ST} = 1.07$ gm/cm^3.

Therefore,

$$W_B = 1.8 \text{ gm/cm}^3 \; V_B$$

and

$$W_{ST} = 1.07 \text{ gm/cm}^3 \; V_{ST}.$$

Substituting for W_B and W_{ST} from Equations 3 and 4 produces:

$$0.43 \; W_{HB} = 1.8 \text{ gm/cm}^3 \; V_B \qquad (5)$$

and

$$0.57 \; W_{HB} = 1.07 \text{ gm/cm}^3 \; V_S. \qquad (6)$$

Since $V_{HB} = V_B + V_{ST}$ (Equation 1), Equation 5 and 6 must be divided by 1.8 gm/cm^3 and 1.07 gm/cm^3, respectively, or

$$0.2389 \text{ gm/cm}^3 \; W_{HB} = V_B \qquad (7)$$

and

$$0.5327 \text{ gm/cm}^3 \; W_{HB} = V_{ST}. \qquad (8)$$

Adding Equation 7 and 8 yields

$$0.7716 \text{ gm/cm}^3 \; W_{HB} = V_{HB}; \qquad (9)$$

but, knowing that

$$V_{HB} \text{ (for sitting man)} = 63835.05 \text{ cm}^3$$

and

$$V_{HB} \text{ (for standing man)} = 61147.76 \text{ cm}^3,$$

we can substitute in Equation 9 and determine that

$$W_{HB} \text{ (Sitting Man)} = \frac{63835.05 \text{ cm}^3}{0.7715 \text{ cm}} = 82.73075 \text{ Kg (182.39 lb)}$$

and

$$W_{HB} \text{ (Standing Man)} = \frac{61147.76 \text{ cm}^3}{0.7716 \text{ gm}} = 79.24800 \text{ Kg (174.412 lb)}$$

Consequently, substituting the values of W_{HB} into Equations 7 and 8 respectively, yields (for sitting man):

$$V_B = (0.2389 \text{ gm/cm}^3)\ (82730.75 \text{ gm}) = 19764.38 \text{ cm}^3$$

and

$$V_{ST} = (0.5327 \text{ gm/cm}^3)\ (82730.75 \text{ gm}) = 44070.67 \text{ cm}^3;$$

and (for standing man):

$$V_B = (0.2389 \text{ gm/cm}^3)\ (79248.00 \text{ gm}) = 18932.35 \text{ cm}^3$$

and

$$V_{ST} = (0.5327 \text{ gm/cm}^3)\ (79248.00 \text{ gm}) = 42215.41 \text{ cm}^3.$$

For the sitting man the % bone by volume, using Equation 1 is

$$\frac{V_B}{V_{HB}} = \frac{19764.38 \text{ cm}^3}{63835.05 \text{ cm}^3} = 0.3096 \text{ or } 30.96 \%$$

the % soft tissue by volume (also using Equation 1) is

$$\frac{V_{ST}}{V_{HB}} = \frac{44070.67\ cm^3}{63835.05\ cm^3} = 0.6904 \text{ or } 69.04\ \%.$$

The same percentages hold true for the standing man:

$$\frac{V_B}{V_{HB}} = \frac{18932.85\ cm^3}{61147.76\ cm^3} = 0.3096 \text{ or } 30.96\ \%$$

and

$$\frac{V_{ST}}{V_{HB}} = \frac{42215.41\ cm^3}{61147.76\ cm^3} = 0.6904 \text{ or } 69.04\ \%.$$

It is now possible to develop an average density of the human body, $\bar{\rho}_{HB}$, which can ultimately be used with modifications in the MOMENT Subroutine of GIFT program to calculate the total body weight, W_{HB}.

Since individual component densities are not available for the individual components as defined, average density, $\bar{\rho}_{HB}$, is multiplied by <u>all</u> components volumes calculated by the MOMENT Subroutine.

The average density, $\bar{\rho}_{HB}$, based on volume considerations, can be computed as follows:

$$\bar{\rho}_{HB} = X\ \rho_B + Y\ \rho_{ST}$$

where: $X = V_B / V_{HB} = 0.3096$, $Y = V_{ST} / V_{HB} = 0.6904$, $\rho_B = 1.8\ gm/cm^3$, and $\rho_{ST} = 1.07\ gm/cm^3$.

$$\bar{\rho}_{HB} = (0.3096)\ (1.8\ gm/cm^3) + (0.6904)\ (1.07\ gm/cm^3)$$

$$= 0.5573\ gm/cm^3 + 0.7387\ gm/cm^3$$

$$\bar{\rho}_{HB} = 1.296\ gm/cm^3$$

This can be verified by rearranging Equation 9

$$0.7716\ cm^3/gm\ W_{HB} = V_{HB}$$

Since $W_{HB} = \bar{\rho}_{HB} V_{HB}$, we find that

$$\bar{\rho}_{HB} = \frac{1}{0.7716} \text{ cm}^3/\text{gm or } 1.296 \text{ gm/cm}^3$$

To be more precise in the weight calculations, the volume of air in an average set of lungs,[3] V_L, was subtracted from the total body volume, V_{HB}, to yield an "adjusted" body volume ($V_{HB} - V_L$). The "adjusted" body volume was multiplied by the average body density, $\bar{\rho}_{HB}$, to produce the "adjusted" body weight, W'_{HB}. In equation form, this is written as follows:

$$W'_{HB} = \bar{\rho}_{HB} (V_{HB} - V_L)$$

where: $\bar{\rho}_{HB} = 1.296 \text{ gm/cm}^3$, $V_{HB} = 63835.05 \text{ cm}^3$, and $V_L = 5500 \text{ cm}^3$,

$$W'_{HB} = 1.296 \text{ gm/cm}^3 \ (58335.05 \text{ cm}^3)$$

(for sitting man)

$$W'_{HB} = 75.60222 \text{ kg } (166.67 \text{ lb})$$

$$W'_{HB} = \bar{\rho}_{HB} (V_{HB} - V_L)$$

where: $\bar{\rho}'_{HB} = 1.296 \text{ gm/cm}^3$, $V_{HB} = 61147.76 \text{ cm}^3$, and $V_L = 5500 \text{ cm}^3$,

$$W'_{HB} = 1.296 \text{ gm/cm}^3 \ (55647.76 \text{ cm}^3)$$

(for standing man)

$$W'_{HB} = 72.11950 \text{ kg } (159.00 \text{ lb})$$

Since the volume of air in the lungs, V_L, is not accounted for in the models because of the way they are constructed, the average body volume, V_{HB}, (which is calculated by the MOMENT Subroutine) is used with the "adjusted" body weight, W'_{HB}, to develop a corrected average human body density, $\bar{\rho}'_{HB}$. This is calculated using the following equation:

[3] The "average" lung capacity, from deepest inspiration to deepest expiration, of a twenty year old male, approximately 1778 mm (70 inches) in height, is 5500 cm^3. Source: Civilian Employees Health Clinic Data.

For sitting man:

$$\bar{\rho}'_{HB} = \frac{W'_{HB}}{V_{HB}}$$

where: $W'_{HB} = 75602.22$ gm and $V_{HB} = 63835.05$ cm^3,

$$\bar{\rho}'_{HB} = \frac{75602.22 \text{ gm}}{63835.05 \text{ cm}^3}$$

$$\bar{\rho}'_{HB} = 1.1843 \text{ gm/cm}^3$$

For standing man:

$$\bar{\rho}'_{HB} = \frac{W'_{HB}}{V_{HB}}$$

where: $W'_{HB} = 72119.50$ gm and $V_{HB} = 61147.76$ cm^3,

$$\bar{\rho}'_{HB} = \frac{72119.50 \text{ gm}}{61147.76}$$

$$\bar{\rho}'_{HB} = 1.1794 \text{ gm/cm}^3$$

If density is an important parameter in determining ballistic resistance of a human body to penetrating mechanisms in a typical weapon system vulnerability study, perhaps the analyst should consider using the "adjusted" average body density $\bar{\rho}'_{HB} \approx 1.18$ gm/cm^3 rather than just the value for soft tissue, 1.07 gm/cm^3, per se. With reference to the initial assumption that the human body is comprised basically of two kinds of tissue - bony and soft, it is recognized an "adjusted" density does not always represent reality when it comes to calculating human body resistance to penetrating mechanisms. A feasible way around this situation is to construct human models with internal skeletons so that resistance of bone and soft tissue can be distinguished; however, the significance of this approach remains undetermined.

APPENDIX B

TABULATION OF COM-GEOM DATA FOR MODEL OF SITTING CREW PERSONNEL (WITH HELMET)

TABLE B-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF SITTING CREW PERSONNEL

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
1	ELLG	0.0000	0.0000	-12.7000	101.6000	0.0000	0.0000	HEAD TOP
		0.0000	88.9000	0.0000	0.0000	0.0000	76.2000	
2	REC	0.0000	0.0000	-50.8000	0.0000	0.0000	38.1000	HEAD MID
		-101.6000	0.0000	0.0000	0.0000	88.9000	0.0000	
3	ELLG	0.0000	0.0000	-50.8000	101.6000	0.0000	0.0000	HEAD LOWER
		0.0000	88.9000	0.0000	0.0000	0.0000	-139.7000	
4	RCC	-25.4000	0.0000	-241.3000	0.0000	0.0000	139.7000	NECK
		63.5000						
5	TEC	99.0600	0.0000	-106.6800	-12.7000	0.0000	55.8800	NOSE TOP
		25.4000	0.0000	0.0000	0.0000	15.2400	0.0000	
		1.6667						
6	ELLG	99.0600	0.0000	-106.6800	24.1300	0.0000	0.0000	NOSE LOWER
		0.0000	15.2400	0.0000	0.0000	0.0000	6.3500	
7	ELLG	95.2500	0.0000	-104.1400	21.5900	0.0000	0.0000	NOSTRILS
		0.0000	20.3200	0.0000	0.0000	0.0000	7.6200	
8	ELLG	12.7000	0.0000	-127.0000	58.4200	0.0000	-60.9600	JAW - CHIN
		0.0000	63.5000	0.0000	30.4800	0.0000	29.2100	
9	ELLG	0.0000	0.0000	-12.7000	92.7100	0.0000	0.0000	BRAIN
		0.0000	81.2800	0.0000	0.0000	0.0000	69.8500	
10	SPH	63.5000	25.4000	-48.2600	20.3200	0.0000	0.0000	LEFT EYE
11	SPH	63.5000	-25.4000	-48.2600	20.3200	0.0000	0.0000	RIGHT EYE
12	ELLG	0.0000	88.9000	-57.1500	-25.4000	16.5100	27.9400	LFT OUTEAR
		13.8430	21.2852	0.0000	-14.4272	9.3726	-18.6690	
13	ELLG	5.0800	93.9800	-60.9600	-25.4000	16.5100	27.9400	-LFT EAR
		13.8430	21.2852	0.0000	-14.4272	9.3726	-18.6690	
14	ELLG	0.0000	-88.9000	-57.1500	-25.4000	-16.5100	27.9400	RGT OUTEAR
		-13.8430	21.2852	0.0000	-14.4272	-9.3726	-18.6690	
15	ELLG	5.0800	-93.9800	-60.9600	-25.4000	-16.5100	27.9400	-RGT EAR
		-13.8430	21.2852	0.0000	-14.4272	-9.3726	-18.6690	
16	ELL1	111.7600	48.2600	-50.8000	29.2100	-50.8000	0.0000	-LFT EYE SOCKET
		37.0840						

TABLE B-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF SITTING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
17	ELL1	111.7600	-48.2600	-50.8000	29.2100	50.8000	0.0000	-RGT EYE
		37.0840						SOCKET
18	RAW	142.2400	25.4000	-175.2600	15.8750	0.0000	27.9400	-FOR MOUTH
		-129.5400	0.0000	73.6600	0.0000	-50.8000	0.0000	
19	RPP	-139.7000	139.7000	-139.7000	127.0000	-203.2000	0.0000	-FOR HDTOP
20	ELLG	0.0000	0.0000	-50.8000	129.5400	0.0000	0.0000	OUTRHELM1
		0.0000	119.3800	0.0000	0.0000	0.0000	132.0800	
21	ELLG	0.0000	0.0000	-50.8000	116.8400	0.0000	0.0000	INNRHELM1
		0.0000	106.6800	0.0000	0.0000	0.0000	119.3800	
22	TEC	7.4905	0.0000	-81.9277	-7.4905	0.0000	31.1277	OUTRHELM2
		-138.6967	0.0000	-33.3883	0.0000	131.3307	0.0000	
		1.1001						
23	TEC	7.4905	0.0000	-81.9277	-7.4905	0.0000	31.1277	INNRHELM2
		-126.0754	0.0000	-30.3378	0.0000	118.6307	0.0000	
		1.1001						
24	BOX	214.4624	152.4000	-182.0672	-41.5976	0.0000	172.8648	-HELM SEC1
		0.0000	-304.8000	0.0000	-345.7296	0.0000	-83.1952	
25	ARB8	50.8000	152.4000	-40.6400	152.4000	152.4000	-35.5600	-HELM SEC2
		177.8000	152.4000	-88.9000	38.1000	152.4000	-119.3300	
		50.8000	-152.4000	-40.6400	152.4000	-152.4000	-35.5600	
		177.8000	-152.4000	-88.9000	38.1000	-152.4000	-119.3800	
26	ELLG	-25.4000	0.0000	-292.1000	0.0000	254.0000	0.0000	SHOULDERS
		0.0000	0.0000	88.9000	91.9480	0.0000	0.0000	
27	RPP	-127.0000	101.6000	-266.7000	266.7000	-292.1000	-139.7000	-SHOULDER
28	ELLG	-25.4000	0.0000	-419.1000	0.0000	0.0000	254.0000	THORAX
		0.0000	190.5000	0.0000	107.7341	0.0000	0.0000	
29	TEC	-25.4000	209.5500	-292.1000	0.0000	6.3500	-285.7500	LEFT
		0.0000	44.4500	0.0000	44.4500	0.0000	0.0000	ARM
		1.1666						
30	ELLG	-25.4000	209.5500	-292.1000	44.4500	0.0000	0.0000	LTSHOULDER
		0.0000	44.4500	0.0000	0.0000	0.0000	31.7500	JOINT

TABLE B-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF SITTING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
31	TEC	-25.4000	-209.5500	-292.1000	0.0000	-6.3500	-285.7500	RIGHT
		0.0000	44.4500	0.0000	44.4500	0.0000	0.0000	ARM
		1.1666						
32	ELLG	-25.4000	-209.5500	-292.1000	44.4500	0.0000	0.0000	RTSHOULDER
		0.0000	44.4500	0.0000	0.0000	0.0000	31.7500	JOINT
33	TRC	-25.4000	215.9000	-577.8500	254.0000	0.0000	132.0800	LEFT
		38.1000	31.7500					FOREARM
34	SPH	-25.4000	215.9000	-577.8500	38.1000	0.0000	0.0000	LEFT ELBOW
35	TRC	-25.4000	-215.9000	-577.8500	254.0000	0.0000	132.0800	RIGHT
		38.1000	31.7500					FOREARM
36	SPH	-25.4000	-215.9000	-577.8500	38.1000	0.0000	0.0000	RIGHTELBOW
37	ELLG	257.7871	215.9000	-415.6888	21.1633	0.0000	-46.1823	LEFT
		57.7266	0.0000	26.4541	0.0000	38.1000	0.0000	FIST
38	SPH	236.6264	215.9000	-369.5090	12.7000	0.0000	0.0000	LEFT THUMB
39	RCC	236.6264	215.9000	-369.5090	-26.1849	0.0000	-44.4195	LEFT THUMB
		12.7000						SEC 2
40	ELLG	257.7871	-215.9000	-415.6888	21.1633	0.0000	-46.1823	RIGHT
		57.7266	0.0000	26.4541	0.0000	38.1000	0.0000	FIST
41	SPH	236.6264	-215.9000	-369.5090	12.7000	0.0000	0.0000	RGHT THUMB
42	RCC	236.6264	-215.9000	-369.5090	-26.1849	0.0000	-44.4195	RGHT THUMB
		12.7000						SEC 2
43	REC	-25.4000	0.0000	-774.7000	0.0000	0.0000	203.2000	ABDOMEN
		0.0000	152.4000	0.0000	82.1233	0.0000	0.0000	
44	ELLG	-44.4500	0.0000	-739.7750	88.9000	0.0000	0.0000	PELVIS
		0.0000	177.8000	0.0000	0.0000	0.0000	101.6000	
45	TRC	-44.4500	69.8500	-746.1250	451.7974	108.5672	0.0000	LEFT
		95.2500	57.1500					THIGH
46	SPH	407.3474	178.4172	-746.1250	57.1500	0.0000	0.0000	LEFT KNEE
47	TRC	407.3474	178.4172	-746.1250	0.0000	0.0000	-422.2750	LEFT
		57.1500	38.1000					LEG

TABLE B-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF SITTING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
48	TRC	-44.4500	-69.8500	-746.1250	451.7974	-108.5672	0.0000	RIGHT
		95.2500	57.1500					THIGH
49	SPH	407.3474	-178.4172	-746.1250	57.1500	0.0000	0.0000	RIGHT KNEE
50	TRC	407.3474	-178.4172	-746.1250	0.0000	0.0000	-422.2750	RIGHT
		57.1500	38.1000					LEG
51	RCC	407.3474	178.4172	-1244.6000	0.0000	0.0000	76.2000	LEFT ANKLE
		38.1000						
52	SPH	407.3474	178.4172	-1168.4000	38.1000	0.0000	0.0000	LTANKPIVOT
53	RCC	407.3474	-178.4172	-1244.6000	0.0000	0.0000	76.2000	RGHT ANKLE
		38.1000						
54	SPH	407.3474	-178.4172	-1168.4000	38.1000	0.0000	0.0000	RTANKPIVOT
55	ARB8	573.9714	229.2172	-1244.6000	591.4974	140.3172	-1244.6000	LEFT
		591.4974	140.3172	-1219.2000	573.9714	229.2172	-1231.9000	FOOT
		413.6974	216.5172	-1244.6000	413.6974	140.3172	-1244.6000	
		413.6974	140.3172	-1168.4000	413.6974	216.5172	-1183.5765	
56	ARB8	573.9714	-229.2172	-1244.6000	591.4974	-140.3172	-1244.6000	RIGHT
		591.4974	-140.3172	-1219.2000	573.9714	-229.2172	-1231.9000	FOOT
		413.6974	-216.5172	-1244.6000	413.6974	-140.3172	-1244.6000	
		413.6974	-140.3172	-1168.4000	413.6974	-216.5172	-1183.5765	

TABLE 8-II. REGION COMBINATION TABLE FOR MODEL OF SITTING CREW PERSONNEL

REGION NUMBER	REGION COMBINATION DATA								REMARKS
1	1	-19	-9						HEAD TOP
2	2	-16	-17	-9	-10	-11			HEAD MIDDLE
3	3	-2	-16	-17	-18	19	-9	-10 -11	HEAD LOWER
4	4	-3	-8	-26					NECK
5	5	-3	-6	-7					NOSE UPPER
6	6	-3	-5	-7					NOSE LOWER
7	7	-3							NOSTRILS
8	8	-3							CHIN
9	9	-10	-11	-16	-17				BRAIN
10	10								LEFT EYE
11	11								RIGHT EYE
12	12	-13	-2	-3	-21	-23			LEFT EAR
13									-DUM LT EAR
14	14	-15	-2	-3	-21	-23			RIGHT EAR
15									-DUM RT EAR
16									-DUM LT EYE
17									-DUM RT EYE
18									-DUM MOUTH
19									-DUM HDTOP
20	20	-21	-24						HELM UPRSEC
21									-IN HELM S1
22	22	-23	24	-25					HELM LWRSEC
23									-IN HELM S2
24									-DUM HELMS1
25									-DUM HELMS2
26	26	27	-29	-30	-31	-32			SHOULDERS
27									-DUM SHOULD
28	28	-27	-29	-30	-31	-32	-43		THORAX
29	29	-30	-33	-34					LEFT ARM
30	30								LT SHOULDJT
31	31	-32	-35	-36					RIGHT ARM

TABLE B-II. REGION COMBINATION TABLE FOR MODEL OF SITTING CREW PERSONNEL (CONTINUED)

REGION NUMBER	REGION COMBINATION DATA				REMARKS
32	32				RT SHOULDJT
33	33	-34			LT FOREARM
34	34				LT ELBOW JT
35	35	-36			RT FOREARM
36	36				RT ELBOW JT
37	37	-33	-38	-39	LEFT FIST
38	38	-39			LT THB SC1
39	39				LT THB SC2
40	40	-35	-41	-42	RIGHT FIST
41	41	-42			RT THB SC1
42	42				RT THB SC2
43	43	-45	-48		ABDOMEN
44	44	-43	-45	-48	PELVIS
45	45	-46	-47	-48	LEFT THIGH
46	46				LEFT KNEE
47	47	-46	-51	-52	LEFT LEG
48	48	-49	-50		RIGHT THIGH
49	49				RIGHT KNEE
50	50	-49	-53	-54	RIGHT LEG
51	51	-52	-55		LEFT ANKLE
52	52				LT ANKLE JT
53	53	-54	-56		RIGHT ANKLE
54	54				RT ANKLE JT
55	55	-52			LEFT FOOT
56	56	-54			RIGHT FOOT

TABLE B-III. REGION IDENTIFICATION TABLE FOR MODEL OF SITTING CREW PERSONNEL

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
1	1		TOP OF HEAD - SKULL	81	100
2	1		MIDDLE OF HEAD - SKULL	81	100
3	1		BOTTOM OF HEAD - SKULL	81	100
4	2		NECK	82	100
5	3		NOSE - UPPER	83	25
6	3		NOSE - LOWER	83	25
7	3		NOSTRILS	83	25
8	4		LOWER JAW - CHIN	84	100
9	5		BRAIN	85	100
10	6		LEFT EYE	86	100
11	6		RIGHT EYE	86	100
12	7		LEFT EAR	83	100
13	111		-DUMMY LEFT EAR		
14	7		RIGHT EAR	83	100
15	111		-DUMMY RIGHT EAR		
16	111		-DUMMY LEFT EYE SOCKET		
17	111		-DUMMY RIGHT EYE SOCKET		
18	111		-DUMMY (SHAPES MOUTH)		
19	111		-DUMMY HEAD TOP		
20	8		HELMET UPPER SECTION	77	100
21	111		-DUMMY HELMET (INSIDE SECTION 1)		
22	8		HELMET LOWER SECTION	77	100
23	111		-DUMMY HELMET (INSIDE SECTION 2)		
24	111		-DUMMY HELMET (SHAPES SECTION 1)		
25	111		-DUMMY HELMET (SHAPES SECTION 2)		
26	9		SHOULDERS	87	100
27	111		-DUMMY (SHAPES THE UPPER TORSO)		
28	10		THORAX	88	100
29	11		LEFT ARM	89	100
30	9		LEFT SHOULDER JOINT	89	100
31	11		RIGHT ARM	89	100

TABLE B-III. REGION IDENTIFICATION TABLE FOR MODEL OF SITTING CREW PERSONNEL (CONTINUED)

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
32	9		RIGHT SHOULDER JOINT	89	100
33	11		LEFT FOREARM	89	100
34	11		LEFT ELBOW JOINT	89	100
35	11		RIGHT FOREARM	89	100
36	11		RIGHT ELBOW JOINT	89	100
37	11		LEFT FIST	89	100
38	11		LEFT THUMB SEC 1	89	100
39	11		LEFT THUMB SEC 2	89	100
40	11		RIGHT FIST	89	100
41	11		RIGHT THUMB SEC 1	89	100
42	11		RIGHT THUMB SEC 2	89	100
43	12		ABDOMEN	90	100
44	13		PELVIS	91	100
45	14		LEFT THIGH	92	100
46	14		LEFT KNEE JOINT	92	100
47	14		LEFT LEG	92	100
48	14		RIGHT THIGH	92	100
49	14		RIGHT KNEE JOINT	92	100
50	14		RIGHT LEG	92	100
51	14		LEFT ANKLE	92	100
52	14		LEFT ANKLE JOINT	92	100
53	14		RIGHT ANKLE	92	100
54	14		RIGHT ANKLE JOINT	92	100
55	14		LEFT FOOT	92	100
56	14		RIGHT FOOT	92	100

TABLE B-IV. REGION IDENTIFICATION TABLE FOR MODEL OF SITTING CREW PERSONNEL ORDERED BY ITEM NUMBER

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
1	1		TOP OF HEAD - SKULL	81	100
2	1		MIDDLE OF HEAD - SKULL	81	100
3	1		BOTTOM OF HEAD - SKULL	81	100
4	2		NECK	82	100
5	3		NOSE - UPPER	83	25
6	3		NOSE - LOWER	83	25
7	3		NOSTRILS	83	25
8	4		LOWER JAW - CHIN	84	100
9	5		BRAIN	85	100
10	6		LEFT EYE	86	100
11	6		RIGHT EYE	86	100
12	7		LEFT EAR	83	100
14	7		RIGHT EAR	83	100
20	8		HELMET UPPER SECTION	77	100
22	8		HELMET LOWER SECTION	77	100
26	9		SHOULDERS	87	100
30	9		LEFT SHOULDER JOINT	89	100
32	9		RIGHT SHOULDER JOINT	89	100
28	10		THORAX	88	100
29	11		LEFT ARM	89	100
31	11		RIGHT ARM	89	100
33	11		LEFT FOREARM	89	100
34	11		LEFT ELBOW JOINT	89	100
35	11		RIGHT FOREARM	89	100
36	11		RIGHT ELBOW JOINT	89	100
37	11		LEFT FIST	89	100
38	11		LEFT THUMB SEC 1	89	100
39	11		LEFT THUMB SEC 2	89	100
40	11		RIGHT FIST	89	100
41	11		RIGHT THUMB SEC 1	89	100
42	11		RIGHT THUMB SEC 2	89	100

TABLE B-IV. REGION IDENTIFICATION TABLE FOR MODEL OF SITTING CREW PERSONNEL ORDERED BY ITEM NUMBER (CONTINUED)

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
43	12		ABDOMEN	90	100
44	13		PELVIS	91	100
45	14		LEFT THIGH	92	100
46	14		LEFT KNEE JOINT	92	100
47	14		LEFT LEG	92	100
48	14		RIGHT THIGH	92	100
49	14		RIGHT KNEE JOINT	92	100
50	14		RIGHT LEG	92	100
51	14		LEFT ANKLE	92	100
52	14		LEFT ANKLE JOINT	92	100
53	14		RIGHT ANKLE	92	100
54	14		RIGHT ANKLE JOINT	92	100
55	14		LEFT FOOT	92	100
56	14		RIGHT FOOT	92	100
13	111		-DUMMY LEFT EAR		
15	111		-DUMMY RIGHT EAR		
16	111		-DUMMY LEFT EYE SOCKET		
17	111		-DUMMY RIGHT EYE SOCKET		
18	111		-DUMMY (SHAPES MOUTH)		
19	111		-DUMMY HEAD TOP		
21	111		-DUMMY HELMET (INSIDE SECTION 1)		
23	111		-DUMMY HELMET (INSIDE SECTION 2)		
24	111		-DUMMY HELMET (SHAPES SECTION 1)		
25	111		-DUMMY HELMET (SHAPES SECTION 2)		
27	111		-DUMMY (SHAPES THE UPPER TORSO)		

APPENDIX C

TABULATION OF COM-GEOM DATA FOR MODEL OF STANDING CREW PERSONNEL (WITH HELMET)

TABLE C-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF STANDING CREW PERSONNEL

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
1	ELLG	0.0000	0.0000	-12.7000	101.6000	0.0000	0.0000	HEAD TOP
		0.0000	88.9000	0.0000	0.0000	0.0000	76.2000	
2	REC	0.0000	0.0000	-50.8000	0.0000	0.0000	38.1000	HEAD MID
		-101.6000	0.0000	0.0000	0.0000	88.9000	0.0000	
3	ELLG	0.0000	0.0000	-50.8000	101.6000	0.0000	0.0000	HEAD LOWER
		0.0000	88.9000	0.0000	0.0000	0.0000	-139.7000	
4	RCC	-25.4000	0.0000	-241.3000	0.0000	0.0000	139.7000	NECK
		63.5000						
5	TEC	99.0600	0.0000	-106.6800	-12.7000	0.0000	55.8800	NOSE TOP
		25.4000	0.0000	0.0000	0.0000	15.2400	0.0000	
		1.6667						
6	ELLG	99.0600	0.0000	-106.6800	.2413	0.0000	0.0000	NOSE LOWER
		0.0000	15.2400	0.0000	0.0000	0.0000	6.3500	
7	ELLG	95.2500	0.0000	-104.1400	21.5900	0.0000	0.0000	NOSTRILS
		0.0000	20.3200	0.0000	0.0000	0.0000	7.6200	
8	ELLG	12.7000	0.0000	-127.0000	58.4200	0.0000	-60.9600	JAW - CHIN
		0.0000	63.5000	0.0000	30.4800	0.0000	29.2100	
9	ELLG	0.0000	0.0000	-12.7000	92.7100	0.0000	0.0000	BRAIN
		0.0000	81.2800	0.0000	0.0000	0.0000	69.8500	
10	SPH	63.5000	25.4000	-48.2600	20.3200	0.0000	0.0000	LEFT EYE
11	SPH	63.5000	-25.4000	-48.2600	20.3200	0.0000	0.0000	RIGHT EYE
12	ELLG	0.0000	88.9000	-57.1500	-25.4000	16.5100	27.9400	LFT OUTEAR
		13.8430	21.2852	0.0000	-14.4272	9.3726	-18.6690	
13	ELLG	5.0800	93.9800	-60.9600	-25.4000	16.5100	27.9400	-LFT EAR
		13.8430	21.2852	0.0000	-14.4272	9.3726	-18.6690	
14	ELLG	0.0000	-88.9000	-57.1500	-25.4000	-16.5100	27.9400	RGT OUTEAR
		-13.8430	21.2852	0.0000	-14.4272	-9.3726	-18.6690	
15	ELLG	5.0800	-93.9800	-60.9600	-25.4000	-16.5100	27.9400	-RGT EAR
		-13.8430	21.2852	0.0000	-14.4272	-9.3726	-18.6690	
16	ELL1	111.7600	48.2600	-50.8000	29.2100	-50.8000	0.0000	-LFT EYE SOCKET
		37.0840						

TABLE C-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF STANDING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
17	ELL1	111.7600	-48.2600	-50.8000	29.2100	50.8000	0.0000	-RGT EYE SOCKET
		37.0840						
18	RAW	142.2400	25.4000	-175.2600	15.8750	0.0000	27.9400	-FOR MOUTH
		-129.5400	0.0000	73.6600	0.0000	-50.8000	0.0000	
19	RPP	-139.7000	139.7000	-139.7000	127.0000	-203.2000	0.0000	-FOR HDTOP
20	ELLG	0.0000	0.0000	-50.8000	129.5400	0.0000	0.0000	OUTRHELM1
		0.0000	119.3800	0.0000	0.0000	0.0000	132.0800	
21	ELLG	0.0000	0.0000	-50.8000	116.8400	0.0000	0.0000	INNRHELM1
		0.0000	106.6800	0.0000	0.0000	0.0000	119.3800	
22	TEC	7.4905	0.0000	-81.9277	-7.4905	0.0000	31.1277	OUTRHELM2
		-138.5392	0.0000	-33.3375	0.0000	131.3307	0.0000	
		1.1001						
23	TEC	7.4905	0.0000	-81.9277	-7.4905	0.0000	31.1277	INNRHELM2
		-125.9434	0.0000	-30.3073	0.0000	118.6307	0.0000	
		1.1001						
24	BOX	214.4624	152.4000	-182.0672	-41.5976	0.0000	172.8648	-HELM SEC1
		0.0000	-304.8000	0.0000	-345.7296	0.0000	-83.1952	
25	ARB8	50.8000	152.4000	-40.6400	152.4000	152.4000	-35.5600	-HELM SEC2
		177.8000	152.4000	-88.9000	38.1000	152.4000	-119.3800	
		50.8000	-152.4000	-40.6400	152.4000	-152.4000	-35.5600	
		177.8000	-152.4000	-88.9000	38.1000	-152.4000	-119.3800	
26	ELLG	-25.4000	0.0000	-292.1000	0.0000	254.0000	0.0000	SHOULDER
		0.0000	0.0000	88.9000	91.9480	0.0000	0.0000	
27	RPP	-127.0000	101.6000	-266.7000	266.7000	-292.1000	-139.7000	-SHOULDER
28	ELLG	-25.4000	0.0000	-419.1000	0.0000	0.0000	254.0000	THORAX
		0.0000	190.5000	0.0000	107.7341	0.0000	0.0000	
29	TGC	-25.4000	209.5500	-292.1000	0.0000	6.3500	-317.5000	LEFT
		0.0000	44.4500	0.0000	44.4500	0.0000	0.0000	ARM
		38.1000	38.1000					
30	ELLG	-25.4000	209.5500	-292.1000	44.4500	0.0000	0.0000	LTSHOULDER
		0.0000	44.4500	0.0000	0.0000	0.0000	31.7500	JOINT

TABLE C-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF STANDING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
31	TGC	-25.4000	-209.5500	-292.1000	0.0000	-6.3500	-317.5000	RIGHT
		0.0000	-44.4500	0.0000	44.4500	0.0000	0.0000	ARM
		38.1000	38.1000					
32	ELLG	-25.4000	-209.5500	-292.1000	44.4500	0.0000	0.0000	RTSHOULDER
		0.0000	44.4500	0.0000	0.0000	0.0000	31.7500	JOINT
33	TGC	-25.4000	215.9000	-609.6000	0.0000	-6.3500	-241.3000	LEFT
		0.0000	38.1000	0.0000	38.1000	0.0000	0.0000	FOREARM
		25.4000	35.5600					
34	SPH	-25.4000	215.9000	-609.6000	38.1000	0.0000	0.0000	LEFT ELBOW
35	TGC	-25.4000	-215.9000	-609.6000	0.0000	6.3500	-241.3000	RIGHT
		0.0000	-38.1000	0.0000	38.1000	0.0000	0.0000	FOREARM
		25.4000	35.5600					
36	SPH	-25.4000	-215.9000	-609.6000	38.1000	0.0000	0.0000	RIGHTELBOW
37	TGC	-25.4000	209.5500	-850.9000	0.0000	12.7000	-101.6000	LEFT
		0.0000	25.4000	0.0000	35.5600	0.0000	0.0000	PALM
		12.7000	44.4500					
38	ELLG	-25.4000	209.5500	-850.9000	57.1500	0.0000	-113.4135	LEFT
		15.8775	0.0000	8.0010	0.0000	12.7000	0.0000	THUMB
39	RPP	-101.6000	0.0000	190.5000	228.6000	-850.9000	-711.2000	-SHP THUMB
40	ELLG	7.9375	222.2500	-952.5000	0.0000	-25.4000	-81.2800	LEFT FIRST
		0.0000	-11.4300	3.5712	10.1600	0.0000	0.0000	FINGER
41	ELLG	-14.2875	222.2500	-952.5000	0.0000	0.0000	-93.9800	LFT SECOND
		0.0000	12.7000	0.0000	10.1600	0.0000	0.0000	FINGER
42	ELLG	-36.5125	222.2500	-952.5000	0.0000	0.0000	-86.3600	LFT THIRD
		0.0000	11.4300	0.0000	10.1600	0.0000	0.0000	FINGER
43	ELLG	-58.7375	222.2500	-952.5000	0.0000	0.0000	-63.5000	LFT FOURTH
		0.0000	10.1600	0.0000	10.1600	0.0000	0.0000	FINGER
44	RPP	-101.6000	25.4000	203.2000	304.8000	-952.5000	-508.0000	-SHP FNGRS
45	TGC	-25.4000	-209.5500	-850.9000	0.0000	-12.7000	-101.6000	RIGHT
		0.0000	-25.4000	0.0000	35.5600	0.0000	0.0000	PALM
		12.7000	44.4500					

TABLE C-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF STANDING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
46	ELLG	-25.4000	-209.5500	-850.9000	57.1500	0.0000	-113.4135	RIGHT
		-15.8775	0.0000	-8.0010	0.0000	12.7000	0.0000	THUMB
47	RPP	-101.6000	0.0000	-228.6000	-190.5000	-850.9000	-711.2000	-SHP THUMB
48	ELLG	7.9375	-222.2500	-952.5000	0.0000	25.4000	-81.2800	RGHT FIRST
		0.0000	11.4300	3.5712	10.1600	0.0000	0.0000	FINGER
49	ELLG	-14.2875	-222.2500	-952.5000	0.0000	0.0000	-93.9800	RGT SECOND
		0.0000	12.7000	0.0000	10.1600	0.0000	0.0000	FINGER
50	ELLG	-36.5125	-222.2500	-952.5000	0.0000	0.0000	-86.3600	RGT THIRD
		0.0000	11.4300	0.0000	10.1600	0.0000	0.0000	FINGER
51	ELLG	-58.7375	-222.2500	-952.5000	0.0000	0.0000	-63.5000	RGT FOURTH
		0.0000	10.1600	0.0000	10.1600	0.0000	0.0000	FINGER
52	RPP	-101.6000	25.4000	-304.8000	-203.2000	-952.5000	-508.0000	-SHP FNGRS
53	REC	-25.4000	0.0000	-739.7750	0.0000	0.0000	203.2000	ABDOMEN
		0.0000	152.4000	0.0000	69.8500	0.0000	0.0000	
54	ELLG	-38.1000	0.0000	-739.7750	92.0750	0.0000	0.0000	PELVIS
		0.0000	168.2750	0.0000	0.0000	0.0000	123.8250	
55	TGC	-38.1000	84.1375	-739.7750	-6.3500	0.0000	-469.9000	LEFT
		0.0000	84.1375	0.0000	81.2673	0.0000	0.0000	THIGH
		57.1500	57.1500					
56	TGC	-38.1000	-84.1375	-739.7750	-6.3500	0.0000	-469.9000	RIGHT
		0.0000	84.1375	0.0000	81.2673	0.0000	0.0000	THIGH
		57.1500	57.1500					
57	TRC	-44.4500	84.1375	-1209.6750	0.0000	0.0000	-406.4000	LEFT
		57.1500	38.1000					LEG
58	TRC	-44.4500	-84.1375	-1209.6750	0.0000	0.0000	-406.4000	RIGHT
		57.1500	38.1000					LEG
59	RCC	-44.4500	84.1375	-1616.0750	0.0000	0.0000	-76.2000	LEFT
		38.1000						ANKLE
60	RCC	-44.4500	-84.1375	-1616.0750	0.0000	0.0000	-76.2000	RIGHT
		38.1000						ANKLE

TABLE C-I. GEOMETRIC SOLIDS COMPRISING COMPUTER MODEL OF STANDING CREW PERSONNEL (CONTINUED)

SOLID NUM	TYPE	SOLID PARAMETERS						REMARKS
61	ARB8	139.7000	46.0375	-1692.2750	122.1740	134.9375	-1692.2750	LEFT
		-38.1000	122.2375	-1692.2750	-38.1000	46.0375	-1692.2750	FOOT
		139.7000	46.0375	-1666.8750	122.1740	134.9375	-1679.5750	
		-38.1000	122.2375	-1631.2515	-38.1000	46.0375	-1616.0750	
62	ARB8	139.7000	-46.0375	-1692.2750	-38.1000	-46.0375	-1692.2750	RIGHT
		-38.1000	-122.2375	-1692.2750	122.1740	-134.9375	-1692.2750	FOOT
		139.7000	-46.0375	-1666.8750	-38.1000	-46.0375	-1616.0750	
		-38.1000	-122.2375	-1631.2515	122.1740	-134.9375	-1679.5750	

TABLE C-II. REGION COMBINATION TABLE FOR MODEL OF STANDING CREW PERSONNEL

REGION NUMBER	REGION COMBINATION DATA								REMARKS
1	1	-9	-19						HEAD TOP
2	2	-9	-10	-11	-16	-17			HEAD MIDDLE
3	3	-2	-9	-10	-11	-16	-17	-18	19 HEAD LOWER
4	4	-3	-8	-26					NECK
5	5	-3	-6	-7					NOSE UPPER
6	6	-3	-5	-7					NOSE LOWER
7	7	-3							NOSTRILS
8	8	-3							CHIN
9	9	-10	-11	-16	-17				BRAIN
10	10								LEFT EYE
11	11								RIGHT EYE
12	12	-2	-3	-13	-21	-23			LEFT EAR
13									-DUM LT EAR
14	14	-2	-3	-15	-21	-23			RIGHT EAR
15									-DUM LT EYE
16									-DUM LT EYE
17									-DUM RT EYE
18									-DUM MOUTH
19									-DUM HDTOP
20	20	-21	-24						HELM UPRSEC
21									-IN HELM S1
22	22	-23	24	-25					HELM LWRSEC
23									-IN HELM S2
24									-DUM HELMS1
25									-DUM HELMS2
26	26	27	-29	-30	-31	-32			SHOULDERS
27									-DUM SHOULD
28	28	-27	-29	-30	-31	-32	-53		THORAX
29	29	-30	-33	-34					LEFT ARM
30	30								LT SHOULDJT
31	31	-32	-35	-36					RIGHT ARM

TABLE C-II. REGION COMBINATION TABLE FOR MODEL OF STANDING CREW PERSONNEL (CONTINUED)

REGION NUMBER	REGION COMBINATION DATA				REMARKS
32	32				RT SHOULDJT
33	33	-34			LFT FOREARM
34	34				LT ELBOW JT
35	35	-36			RGT FOREARM
36	36				RT ELBOW JT
37	37				LEFT PALM
38	38	-37	-39	-40	LEFT THUMB
39					-SHP THUMB
40	40	-44			LT 1ST FNGR
41	41	-44			LT 2ND FNGR
42	42	-44			LT 3RD FNGR
43	43	-44			LT 4TH FNGR
44					-SHP FINGER
45	45				RIGHT PALM
46	46	-45	-47	-48	RIGHT THUMB
47					-SHP THUMB
48	48	-52			RT 1ST FNGR
49	49	-52			RT 2ND FNGR
50	50	-52			RT 3RD FNGR
51	51	-52			RT 4TH FNGR
52					-SHP FINGER
53	53				ABDOMEN
54	54	-53	-55	-56	PELVIS
55	55	-57			LEFT THIGH
56	56	-58			RIGHT THIGH
57	57	-59			LEFT LEG
58	58	-60			RIGHT LEG
59	59	-61			LEFT ANKLE
60	60	-62			RIGHT ANKLE
61	61				LEFT FOOT
62	62				RIGHT FOOT

TABLE C-III. REGION IDENTIFICATION TABLE FOR MODEL OF STANDING CREW PERSONNEL

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
1	1		TOP OF HEAD - SKULL	81	100
2	1		MIDDLE OF HEAD - SKULL	81	100
3	1		BOTTOM OF HEAD - SKULL	81	100
4	2		NECK	82	100
5	3		NOSE - UPPER	83	25
6	3		NOSE - LOWER	83	25
7	3		NOSTRILS	83	25
8	4		LOWER JAW - CHIN	84	100
9	5		BRAIN	85	100
10	6		LEFT EYE	86	100
11	6		RIGHT EYE	86	100
12	7		LEFT EAR	83	100
13	111		-DUMMY LEFT EAR		
14	7		RIGHT EAR	83	100
15	111		-DUMMY RIGHT EAR		
16	111		-DUMMY LEFT EYE SOCKET		
17	111		-DUMMY RIGHT EYE SOCKET		
18	111		-DUMMY MOUTH		
19	111		-DUMMY HEAD TOP		
20	8		HELMET UPPER SECTION	77	100
21	111		-DUMMY HELMET (INSIDE SECTION 1)		
22	8		HELMET LOWER SECTION	77	100
23	111		-DUMMY HELMET (INSIDE SECTION 2)		
24	111		-DUMMY HELMET (SHAPES SECTION 1)		
25	111		-DUMMY HELMET (SHAPES SECTION 2)		
26	9		SHOULDERS	87	100
27	111		-DUMMY (SHAPES THE UPPER TORSO)		
28	10		THORAX	88	100
29	11		LEFT ARM	89	100
30	9		LEFT SHOULDER JOINT	89	100
31	11		RIGHT ARM	89	100

TABLE C-III. REGION IDENTIFICATION TABLE FOR MODEL OF STANDING CREW PERSONNEL (CONTINUED)

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
32	9		RIGHT SHOULDER JOINT	89	100
33	11		LEFT FOREARM	89	100
34	11		LEFT ELBOW JOINT	89	100
35	11		RIGHT FOREARM	89	100
36	11		RIGHT ELBOW JOINT	89	100
37	11		LEFT PALM	89	100
38	11		LEFT THUMB	89	100
39	111		-DUMMY (SHAPES LEFT THUMB)		
40	11		LEFT FIRST FINGER	89	100
41	11		LEFT SECOND FINGER	89	100
42	11		LEFT THIRD FINGER	89	100
43	11		LEFT FOURTH FINGER	89	100
44	111		-DUMMY (SHAPES LEFT FINGERS)		
45	11		RIGHT PALM	89	100
46	11		RIGHT THUMB	89	100
47	111		-DUMMY (SHAPES RIGHT THUMB)		
48	11		RIGHT FIRST FINGER	89	100
49	11		RIGHT SECOND FINGER	89	100
50	11		RIGHT THIRD FINGER	89	100
51	11		RIGHT FOURTH FINGER	89	100
52	111		-DUMMY (SHAPES RIGHT FINGERS)		
53	12		ABDOMEN	90	100
54	13		PELVIS	91	100
55	14		LEFT THIGH	92	100
56	14		RIGHT THIGH	92	100
57	14		LEFT LEG	92	100
58	14		RIGHT LEG	92	100
59	14		LEFT ANKLE	92	100
60	14		RIGHT ANKLE	92	100
61	14		LEFT FOOT	92	100
62	14		RIGHT FOOT	92	100

TABLE C-IV. REGION IDENTIFICATION TABLE FOR MODEL OF STANDING CREW PERSONNEL ORDERED BY ITEM NUMBER

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
1	1		TOP OF HEAD - SKULL	81	100
2	1		MIDDLE OF HEAD - SKULL	81	100
3	1		BOTTOM OF HEAD - SKULL	81	100
4	2		NECK	82	100
5	3		NOSE - UPPER	83	25
6	3		NOSE - LOWER	83	25
7	3		NOSTRILS	83	25
8	4		LOWER JAW - CHIN	84	100
9	5		BRAIN	85	100
10	6		LEFT EYE	86	100
11	6		RIGHT EYE	86	100
12	7		LEFT EAR	83	100
14	7		RIGHT EAR	83	100
20	8		HELMET UPPER SECTION	77	100
22	8		HELMET LOWER SECTION	77	100
26	9		SHOULDERS	87	100
30	9		LEFT SHOULDER JOINT	89	100
32	9		RIGHT SHOULDER JOINT	89	100
28	10		THORAX	88	100
29	11		LEFT ARM	89	100
31	11		RIGHT ARM	89	100
33	11		LEFT FOREARM	89	100
34	11		LEFT ELBOW JOINT	89	100
35	11		RIGHT FOREARM	89	100
36	11		RIGHT ELBOW JOINT	89	100
37	11		LEFT PALM	89	100
38	11		LEFT THUMB	89	100
40	11		LEFT FIRST FINGER	89	100
41	11		LEFT SECOND FINGER	89	100
42	11		LEFT THIRD FINGER	89	100
43	11		LEFT FOURTH FINGER	89	100

TABLE C-IV. REGION IDENTIFICATION TABLE FOR MODEL OF STANDING CREW PERSONNEL ORDERED BY ITEM NUMBER (CONTINUED)

REGION NUMBER	ITEM CODE	SPACE CODE	DESCRIPTION	MATERIAL CODE	LOS PERCENT
45	11		RIGHT PALM	89	100
46	11		RIGHT THUMB	89	100
48	11		RIGHT FIRST FINGER	89	100
49	11		RIGHT SECOND FINGER	89	100
50	11		RIGHT THIRD FINGER	89	100
51	11		RIGHT FOURTH FINGER	89	100
53	12		ABDOMEN	90	100
54	13		PELVIS	91	100
55	14		LEFT THIGH	92	100
56	14		RIGHT THIGH	92	100
57	14		LEFT LEG	92	100
58	14		RIGHT LEG	92	100
59	14		LEFT ANKLE	92	100
60	14		RIGHT ANKLE	92	100
61	14		LEFT FOOT	92	100
62	14		RIGHT FOOT	92	100
13	111		-DUMMY LEFT EAR		
15	111		-DUMMY RIGHT EAR		
16	111		-DUMMY LEFT EYE SOCKET		
17	111		-DUMMY RIGHT EYE SOCKET		
18	111		-DUMMY MOUTH		
19	111		-DUMMY HEAD TOP		
21	111		-DUMMY HELMET (INSIDE SECTION 1)		
23	111		-DUMMY HELMET (INSIDE SECTION 2)		
24	111		-DUMMY HELMET (SHAPES SECTION 1)		
25	111		-DUMMY HELMET (SHAPES SECTION 2)		
27	111		-DUMMY (SHAPES THE UPPER TORSO)		
39	111		-DUMMY (SHAPES LEFT THUMB)		
44	111		-DUMMY (SHAPES LEFT FINGERS)		
47	111		-DUMMY (SHAPES RIGHT THUMB)		
52	111		-DUMMY (SHAPES RIGHT FINGERS)		

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